Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 95 (2014) 465 – 472
Procedia Engineering
www.elsevier.com/locate/procedia

2nd International Conference on Sustainable Civil Engineering Structures and Construction Materials 2014 (SCESCM 2014)

The influence of compression applied during production to the compression strength of dry concrete: An experimental study

Sulistyana[a], Purwanto[b]*, Vemi Widoanindyawati[b], M. Mirza Abdillah Pratama[b]

[a]*PT. FLYSLAB, Indonesia*
[b]*Diponegoro University, Prof. Soedharto Street, Semarang 50275, Indonesia*

Abstract

Dry concrete is a cementitious material, consisting of aggregates imbedded in a cement matrix. The water cement factor is customary kept low, the compression stress is given to reduce the air voids in the mixture, to enable the entrapped water to optimize the hydration process, and to create more dense material so it will provide a better performance. This study uses 2 types of mix designs and 9 types of compressive stress. The experimental test showed that the greater compressive stress given during the production process increase the compressive strength of the dry concrete until it reaches the optimum point.

Peer-review under responsibility of organizing committee of the 2nd International Conference on Sustainable Civil Engineering Structures and Construction Materials 2014

*Keywords:*Compression stress; entrapped water; cement hydration; air void; compression strength.

1. Introduction

Concrete is one of the more favored building materials for construction because the simplicity in production and ease in obtaining the basic materials. In the past two decades, research and innovations regarding the concrete technology has been concentrated on the optimization of structural elements. Among the most recent developments are the prefabricated concrete elements. The use of prefabricated elements not only shortens the construction time

* Corresponding author. Tel.: +62-813-568-4902; fax: +62-24-764-807-27.
E-mail address: purwatrend@gmail.com

1877-7058
Peer-review under responsibility of organizing committee of the 2nd International Conference on Sustainable Civil Engineering Structures and Construction Materials 2014
doi:10.1016/j.proeng.2014.12.206

on the side, but also ensures a high and consistent production quality. The prefabricated concrete manufacturing process currently uses conventional concrete mixes with a water cement factor (WCF) ranging from 0.50 – 0.65. The manufacture of prefabricated concrete structures as structural elements should be optimizing the performance of materials, the manufacturing methods including the casting, and the choice of proper production equipment. The manufacture of dry concretes with a WCF of 0.20 – 0.40 is one of the viable options to speed up the production, since the elements can be unmolded directly after casting [1]. Dry concrete mixes are used in the concrete prefabrication industry for its effectiveness and time-efficiency.

Dry concrete is a concrete mix with a very high initial consistency when compared to conventional concrete, due to the low water content. However, the dry concrete mix must be sufficiently moist to ensure that the materials in the mixture can be blended well and compacted effectively during casting. The unmolding of casts and dismantling of formwork can be accelerated, and yields in an increase in manufacturing productivity [2]. In terms of costs, the use of dry concrete in construction results in a cost saving of 35% from the reduction of damage due to adhesion to the casting-wall, 10 % from the reduction-time of the use of scaffoldings and another 25 % from the efficiency increase in brick wall works [3]. In usual construction cost is needed so many cost to support the concrete mixing. Commonly, there are 3 cost which are needed, casting wall, scaffolding, and brick wall. But in fact , it was not an efficient thing. Whereas for every that necessary must be given 35% cost for reduction damage.

According to the research conducted by Levitt [4] a concrete mix with a low WCF results in a high degree of difficulty during the mixing. The dry concrete is less dense and compacting by the ordinary method, i.e. vibration or mechanical compacting with a tapping rod, was proven ineffective in increasing the concrete density. The poor compacting further negatively affects the compression strength of the resulting cementitious component. Thus, research work is required to pursue for a more effective dry concrete compaction method. Since dry concrete is produced by different mixing and compacting techniques, the resulting concrete characteristics will differ from the conventional concrete. The techniques that are commonly used are hand ramming, manual compaction and vibration. Research conducted by Baiden et al. [5] showed that the fabrication of dry concrete by the manual compacting methods failed to result in concrete with appropriate quality standards. Studies conducted by Nanni et al. [6] showed that roller compacted concrete having similar characteristics to dry concrete had a higher compression strength as compared to the dry concrete compacted by the application of compression. Meanwhile, research conducted by Pratama et al. [7] proved that the higher the application of compression during the compacting process, the higher the compression strength of the dry concrete.

The purpose of this research was to study and to analyze the influence of the application of compression stresses during casting and compacting of dry concrete. The applied compression stresses were expected to minimize the air void content in the dry concrete, while on the other hand force the free water to react with the cement particles that has not been hydrated. The research was conducted at the Material and Construction Laboratory, Diponegoro University in Semarang, Indonesia.

2. Research procedure

In general, the research procedure is divided into four parts: basic material testing analysis, proportion mix design, the manufacture of test specimens, and testing and data analysis.

2.1. Material examination

The materials used in this study were: the cement, fine aggregates, stone dust, coarse aggregates, and water. The binding agent is PCC (Portland Composite Cement). The fine aggregate is Muntilan sand, originating from the Central Java region. This type of sand is classified as diorite. Meanwhile, the stone dust and crushed stone are diorites as well. The testing results are shown in Table 1. It was seen that the constituent materials are in accordance with the ASTM requirements [8, 9] and PBBI 1971 [10].

Table 1. Result of material examination

Type of examination	Result		
	Sand	Dust stone	Crushed stone
Sieve analysis, Fineness modulus	2.72	2.77	5.67
Fine particle content	1.40%	-	0.46%
Organic materials	Transparent Yellow (No.5)	-	-
Bulk water content	0.45%	1.08%	0.59%
Saturated Surface Dry water content	1.2%	1.23%	1.05%
Bulk specific gravity	2.511	2.508	2.729
SSD specific gravity	2.547	2.599	2.732

2.2. Mix design

The mix design functions as guidance to determine the material proportions within the concrete mix. There are many mix design methods that will result the different mix proportion. From many methods, the researcher prefer to choose one of them which will produce the most optimal composition. The study conducted by Purwanto [11] proved that the mix design of Department of Environment (DOE) method produce the more efficient proportion of cement within the mixture than the ACI method. The mix design results the proportion between the constituent materials of the concrete : cement, sand, dust stone, crushed stone, and water. As the boundary of this study, the proportion between the sand and the dust stone is locked on 50 % : 50 %.

In this study, the proportions of the material for the dry concrete are shown in Table 2. As explained, two types of mix proportions were prepared, mix DC-B having a relatively higher cement content compared to mix DC-A. The effectiveness of applied compression stresses to the increase in compression strength could then be examined.

Table 2. Mix design of dry concrete

No	f'c	Material proportion in weight				
	w/c = 0.4	Cement	Sand	Dust stone	Crushed stone	Water
1	DC-A	1.00	1.60	1.60	4.10	0.47
2	DC-B	1.00	1.42	1.42	3.63	0.46

2.3. Procedure of manufacture the specimens

The specimens used in this study are 100 by 200 mm cylinders. For every type of mix proportion, 9 variations in applied compression stresses were assigned, for which 3 specimens each were prepared. The preparation of cylindrical concrete specimens is divided into two stages: the mixing, and the application of compression stresses for the purpose of compaction. The materials that have been weighed based on the appropriate mix proportion were mixed in a dry condition and put into the concrete mixer. When a homogeneous dry mix was obtained, the mixing water was added and the stirring of the mixer maintained until all the materials were distributed evenly and a homogeneous composition is reached. This process had to be done as fast as possible to prevent excessive evaporation of water due to the surrounding heat. The cylindrical molds were lubricated to prevent attachment of the concrete mix with the molds. The casting of the homogeneous concrete mix was performed in three layers; each layer was pierced with a steel rods as much as 25 times to reduce the air voids in the concrete and to enable the entrapped air to surface. The compacting process was conducted by the Universal Testing Machine (UTM) which is equipped with a compression load readings dial. The applied compression stress could thus be monitored precisely. The compression stresses used in this research were held until 1 minute before they were released. This compression is conducted to achieve a uniform applied compression stress on the specimens. The cylinders' casts were equipped with a steel clamp surrounding the casts to prevent the failure of moulds due to the very high longitudinal stresses originating from the applied compression stress (Figure 1). The specimens were de-moulded after 24 hours. The curing of the concrete samples was performed for approximately 26 days by the water-submerging method. The water temperature was controlled at 28 degrees so that the hydration process was at optimum. A detailed set-up of the compression procedure is shown in Figure 1.

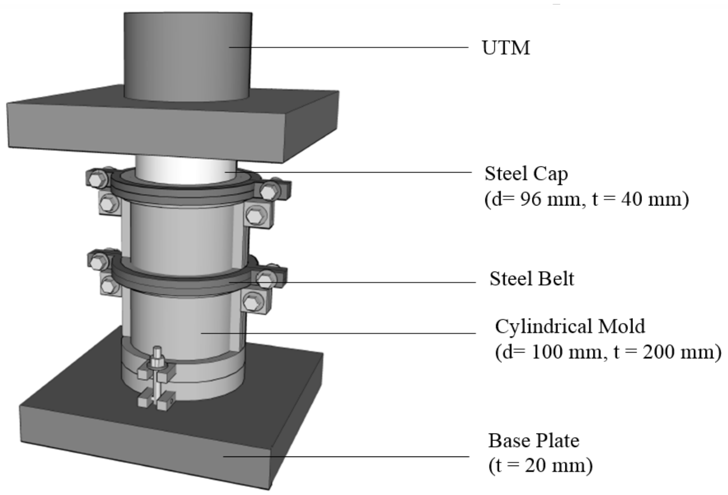

Fig. 1. Set up for compacting of specimens

2.4. Testing procedure

The compression strength testing was conducted by the Universal Testing Machine (UTM) in accordance with the ASTM standard [12]. In addition to the UTM, additional measuring equipment was used in this stage, namely: a load cell with a capacity of 500 kN to record the magnitude of loading during the test, and 2 LVDTs (Linear Variable Differential Transducer) for monitoring the displacement of the test specimen under the increasing loads. The overall test results were recorded by a data logger. All of the samples were tested at the age of 28 days.

3. Experimental test results

3.1. Analysis of the ultimate load respond

Prior to the production of test specimens a preliminary test was performed to obtain the effective maximum applied compression stress for the compacting purposes. It was understood that a maximum compaction will be reached when all voids in the concrete mix are eliminated. This preliminary test was carried out using the exact same concrete mix proportion as in the main research. During the preliminary study the range for the applied compression stress was set from 0 MPa to 50 MPa, with an increment of 10 MPa. These preliminary test results showed that the higher the compression stress applied during the production process, the higher the compression strength of the resulting concrete specimen. From this preliminary test it was found that the effective compression stress during casting was 40 MPa. A convergent state was observed and no increase in compression strength was obtained after to this point, implicating that an effective point for a maximum density of the concrete mix had been reached.

The ultimate load recorded for every specimen was further converted to the compression strength, by dividing the ultimate load by the surface area of the concrete cylinder. The individual compression strengths of each specimen were then normalized by calculating the ratio to the control specimen. The control specimen was used to be the specimen that was compacted with a zero applied compression having the mix proportion DC-A. The normalized compression strength ratios were tabulated against the applied compression stress and are shown in Figure 2.

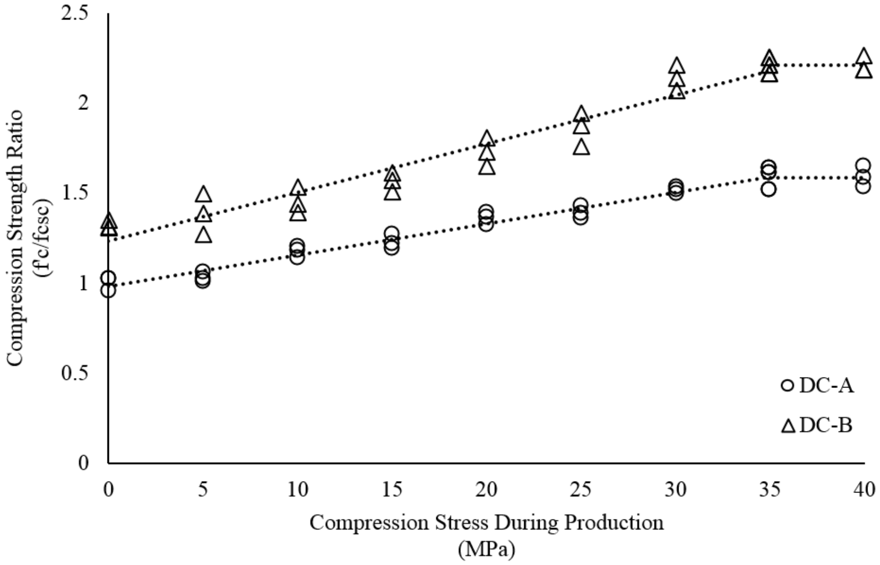

Fig. 2. Compression strength ratios versus applied compression stress for compacting purposes

The result showed that the compression strength increased with the enhancement of the compression stress, applied during the compacting process. The increase in compression strength progressed gradually until it reached the convergence point as obtained in the preliminary study. The explanation lays in the fact that at during the mixing process, the amount of water in the mixture could not completely be accessed for the cement hydration process. Most of the water was trapped in the pores and part of the free water was evaporated during the mixing process. Therefore, the compression stress applied during production was expected to force the water out of the voids and reach the cement particles that have not been hydrated [13]. In addition, the compaction of the concrete mix was aimed to overcome the diversity in grain sizes in the mix, the applied compression stress should force the aggregates mechanically to a denser formation and promote the interlocking between each aggregate particle.

Examining the compression strength behavior of mixes DC-A and DC-B in Figure 2, it is shown that the overall compression strength of the DC-B is higher than the DC-A. This behavior is associated to the higher cement content in DC-B. This finding was underlined by the research conducted by Ghavfoori *et al.* [14], stating that an increase in cement percentage in a concrete mixture increases the compression strength although the composition of the aggregates, relatively to cement, is high. The cement content in cement based material determine the strength of the structure. The hydration process undergoes when the cement particles meet the water and form the binding matrix which gain the strength of the concrete.

Cement particles consist of many silica compounds which form the calcium silica hydrate (CSH) on the hydration process and acts as the binding agent between the particles in the concrete mixture. When the hydration process completely done, the matrix create the stronger bond so the greater strength obtained. This study results the increase of cement percentage by 23.375% increase the compressive strength of dry concrete by 39.2667% at optimum compression stress. Meanwhile, the study conducted by Widyastuti [15] showed that the increase of cement percentage in conventional concrete by 34.159% can increase the compressive strength of 27.146%. If we compare those result studies, we observe that the increase of cement in the dry concrete results the higher compressive strength than the conventional method. It can be analyze that the compression applied during production help the concrete mixture to reach the more optimum strength.

Figure 2 also shows the increment rate of compressive strength of both mixture, the DC-A and DC-B, shows a similar gradient. This was due to both the mix design using the same value of WCF or it can be formulated that the increment rate of compressive strength of the dry concrete is a function of WCF value used. The normalized data showed that mix DC-A had an optimal percentage increase of 48.4% for an applied compression stress of 35 MPa, while mix DC-B exhibited a slightly higher value of 54.0% at 35 MPa applied compression stresses. A convergent state was found prior to this compression stress, resulting in a negligible increase in strength. Evaluating the compression strength behavior for the applied compression stress in the range of 35 MPa to 40 MPa, it was seen that the increase became negligibly small. The mix DC-A shows an increase of 0.014% and the DC-B showed an increase of 0.009%. It can be concluded that the compression strength increase was approximately less than 0.1%, underlining that the optimal applied compression stress was 35 MPa. At this stage, the dry concrete has reached the optimum density; as consequence, the dry concrete has met its optimum compression strength.

The compression strength test result data for both the mix proportions DC-A and DC-B were analyzed statistically to evaluate the spread and standard deviation of the data; it was found that all data were statically valid. The mix DC-B showed a wider data spreading for each variation in applied compression stress as compared to the DC-A mix. This was due to the fact that the mix DC-B had a much coarser constitution, since this mix consisted of a notably higher coarse aggregate content with a lower fine aggregate composition. Coarse aggregates are less effectively compacted, when compared to finer aggregates. The mix DC-B also exhibited a lower workability when compared to mix DC-A. The poor workability results in a higher porosity degree and an uneven specimen surface, which during testing yielded in stress concentrations in the specimen. These effects were studied by Rommel et al.[16, 17] stating that the quality of the dry concrete is influenced by the degree of compaction, the mixture, and the age of the specimens. Furthermore, it was shown that the ineffective compaction causes the concrete to be spongy.

The main aspect of this research lies in its economic potential. The application of the dry concrete has a better economic benefit when compared to conventional concrete. Dry concrete require less resources, including materials and man power. By utilizing the relationship between the applied stresses and increase in strength, one can analyze the effectiveness of dry concrete for commercial purposes. Examining Figure 2, we can produce the same strength of dry concrete with the different mixture, DC-A and DC-B, by applying the appropriate compression stress. This means that the concrete industry can chose between two alternates: having a mix proportion with less cement but with a higher applies compression stress during production, or a higher cement content with lower compression stress. Both factors should easily be convertible to a monetary value: a higher cement content will result in a rise in material cost, but a higher applied compression stress requires more sophisticated production equipment, with stronger casts. It is clearly seen that from the developed curves, the manufacture can produce the same concrete quality by deciding on two variables, the cement content or the applied stress.

Dry concrete is a highly prospective technology that required the further research to be done. The study in mix proportion of the dry concrete should be established in order to obtain the higher strength of the dry concrete. The effective thickness for compaction by cylindrical specimen should be analyze to observe the distribution of stress as the function of the thickness. Scanning Electron Microscope (SEM) can be used considerably to observe the influence of the compression stresses to the microstructure of the dry concrete. The study of the contribution between the density and hydration reactions of the cement as the effect of compression applied due to the increase of compressive strength also required to be studied as well. Besides, the economic analysis is needed to determine the benefit of the present study to the other method especially the conventional concrete.

3.2. Analysis of displacement

The compacting of specimens influenced the density of the produced concrete. The LVDT devices used during the compression strength testing served to record the displacement of the cylinder during the loading progress. The degree of displacement is furthermore a function of the material deformation, also influenced by the void content. The relation between the applied compression stress and the normalized deformation ratio obtained from the tests are presented graphically in Figure 3 and Figure 4.

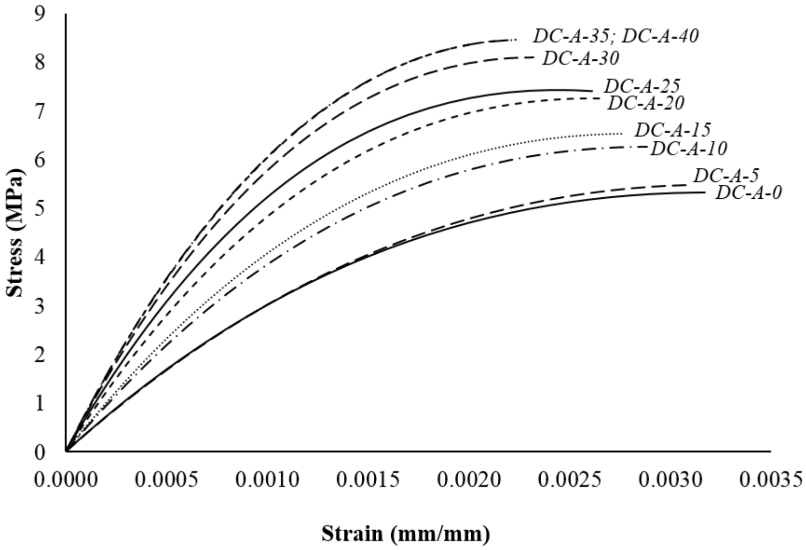

Fig. 3. Strain – Stress Relationship of DC-A mixture

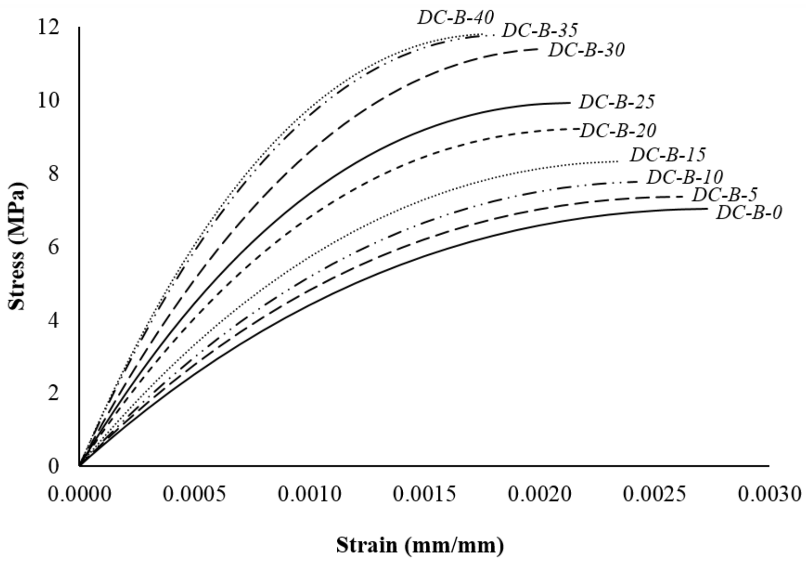

Fig. 4. Strain – Stress Relationship of DC-B mixture

To determine the stress strain relationship of the dry concrete is done by recording the displacement that occurs during loading test until the maximum load achieved. The compression test is done by relatively small velocity in order to obtain a more precise data of displacement. The data that consists of relationship between the magnitude of displacement during the loading is converted into data shows the relationship between stress and strain, so that it can be observed the behavior of the tested dry concrete. Dry concrete which has a higher compressive strength has a small value of the displacement so it has a fewer strain. In the other hand, the dry concrete which has a lower compressive strength has a greater strain so these dry concrete are more ductile rather than the dry concrete which has the higher one. It means that the dry concrete will experience the greater strain before failure.

4. Conclusions

- The applied compression stress during the production process increases the compression strength of dry concrete.
- The characteristics of the mixture influence the workability of the dry concrete. The DC-B has a coarser mixture than the DC-A, and therefore requires a higher compression stress during production to reach a significant increase in percentage of its compression strength.
- The increment rate of compressive strength and the optimum compression stress of the dry concrete functions as the WCF used. The same WCF expected to result the same rate of the compressive strength and the optimum point.
- The optimum level of compression stress for DC-A and DC-B during production is 35 MPa.

Acknowledgements

This research project was supported by PT. Flyslab Indonesia and the Structural and Construction Laboratory Diponegoro University Semarang.

References

[1] T. C. Ling, Effects of compaction method and rubber content on the properties of concrete paving blocks, Construction and Building Materials 28, 2011, pp. 164-175.ASTM C33/03, Standard Spesification for Concrete Aggregate,*Annual Books of ASTM Standards*, USA, 2006.

[2] J. Marchand, H. Hornain, S. Diamond, M. Pigeon, and H. Guiraud, The microstructure of dry concrete products,*Cement and Concrete Research*, Vol. 26 No. 3, 1996, pp. 427-438.

[3] W. E. Willis, An introduction dry-cast concrete, The Aberdeen Group, 1969.

[4] M. Levitt, Precast concrete: Materials, manufacture, properties and usage,*Applied Science Publishers*, 1982.

[5] B. K. Baiden and C. K. O. Asante, Effects of orientation and compaction methods of manufacture on strength properties of sandcrete blocks, *Construction and Building Materials* 18, 2004, pp. 717.

[6] A. Nanni and N. Meamarian, Laboratory consolidation methods applied to compacted concrete for pavement,*ASCE*, 1993, pp. 137-143.

[7] M. M. A. Pratama, V. Widoanindyawati, Studi eksperimental pengaruh tegangan tekan selama proses produksi terhadap kuat tekan dry concrete,Undergraduate Thesis, Diponegoro University, Semarang, Indonesia, 2014.

[8] ASTM C127, Standard Test Method for Spesific Gravity and Absorption of Coarse Aggregate, Annual Books of ASTM Standards, USA, 2006.

[9] ASTM C128, Standard Test Method for Density, Relative Density (Spesific Gravity) and Absorption of Fine Aggregate, Annual Books of ASTM Standards, USA, 2006.

[10] Peraturan Beton Bertulang Indonesia 1971, N.I.-2, Departemen Pekerjaan Umum dan Tenaga Listrik, Indonesia.

[11] Purwanto, Mix Design DOE dan ACI, Pilar Edisi III Tahun II, 1994, pp. 26-30.

[12] ASTM C39/C39M-05, Standard Test Method for Compressive Strenght of Cylindrical Concrete Specimens, Annual Books of ASTM Standards, USA, 2006.

[13] A. Neville, Water and concrete: A love-hate relationship, Concrete International, Vol. 12, 2002, pp. 34-38.

[14] N. Ghavfoori and S. Dutta, Laboratory investigation of compacted no-fines concrete for paving materials, Journal of Civil Engineering Vol. 7 No. 3, 1995.

[15] Widyastuti, Korelasi Waktu terhadap Kuat Tekan Beton Mutu Normal dan Beton Mutu Tinggi, Undergraduate Thesis, Diponegoro University, Semarang, Indonesia, 2010.

[16] E. Rommel, Peningkatan kualitas paving block akibat pemberian variasi tekanan pada proses ppembuatannya, Media Teknik Sipil, Vol. 1, No. 1, Agustus 2003, ISSN 1693-3095.

[17] E. Rommel, Teknologi pembuatan paving block dengan material FCA (Fine Coarse Aggregate), Undergraduate Thesis, Muhammadiyah Malang University, Malang, Indonesia, 2007.